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THE IMPACT OF JP-4/JP-8 CONVERSION ON AIRCRAFT ENGINE EXHAUST EMISSIONS

FUELS BRANCH
FUELS AND LUBRICATION DIVISION

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AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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The proposed conversion of predominant Air Force fuel usage from JP-4 to JP-8 has created the need to examine the dependence of engine pollutant emission on fuel type. Available data concerning the effect of fuel type on emissions has been reviewed. T56 single combustor testing has been undertaken to determine JP-4/JP-8 emission variations over a wide range of simulated engine cycle operating conditions at idle. In addition, a J85-5 engine was tested using JP-4 and JP-8. Results of the previous and new data collectively led to the following conclusions regarding conversion to JP-8: a) HC and CO

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emission changes will depend upon individual combustor design features, b) no change to NO_x emission will occur, and c) an increase in smoke/particulate emissions will result. It is recommended that these findings be incorporated into air quality analytical models to define the overall impact of the proposal conversion. Further, it is recommended that combustor analytical models be employed to attempt prediction of the results described herein. Should these models be successful, analytical prediction of JP-8 emissions from other Air Force engine models may be substituted for more expensive combustor rig or engine testing.

FOREWORD

This report contains the results of an effort to evaluate one aspect of the environmental impact of the proposed conversion from JP-4 to JP-8 as the primary U.S. Air Force jet fuel. The work was performed in the Fuels Branch of the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, under Project 3048, Task 05, and Work Unit Number 72. The overall effort was managed by W.S. Blazowski during the period July 1975 to February 1976.

The author wishes to express his appreciation to the technicians who skillfully accomplished this project. Combustor rig testing was accomplished by H. Reeves, V. Kelly, T. Gootee, and M. Fussel. Engine testing was performed by L. Sauer, F. Bolanger, R. Whitlock, and R. Homer. Exhaust gas analysis was performed by T. Campbell, J. Simmons, and G. Boggs. The author also wishes to acknowledge the engineering support of S. Stumpf, J. Marzeski, D. McErlean, L. Tackett, and F. S. Fahrenbruck in facility management and data reduction.

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INTRODUCTION

In 1973 the Defense Energy Task Force recommended that aggressive action be taken to standardize Department of Defense Fuels to the maximum extent possible.[1] The Joint Logistics Commanders established a Joint Technical Coordinating Group (JTCG) in March 1974 to perform these standardization studies. Consistent with the recommendation of the Defense Energy Task Force, the JTCG recommended that the Air Force should phase in JP-8, MIL-T-83133, as supply conditions permit to replace JP-4, MIL-T-5624 as the standard Air Force turbine fuel. JP-8 is essentially commercial grade Jet A-1 containing two additives presently required in JP-4. The primary purposes of this proposed action are to standardize with Jet A-1 commercial aviation kerosine, to keep pace with the same standardization efforts within NATO, to provide safety improvements, and to be compatible with fuel requirements of high performance aircraft.[2] Further, this action would eliminate expenditures for fuel evaporative control equipment which would otherwise be necessary for compliance with EPA air pollution abatement requirements.[3]

The purpose of this report is to examine the effect of JP-4 to JP-8 conversion on aircraft engine exhaust pollutant emissions. Emissions to be considered are carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x)*, and smoke or particulates. In addition to reviewing the existing data on this matter, combustor rig testing involving a T56 single combustor and engine testing with

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*The symbol NO_x is used to express the sum of NO and NO_2 emissions.

a J85-5 afterburning turbojet were undertaken. In the case of T56 combustor rig studies, a wide variety of idle combustor inlet temperature and pressure conditions were simulated. These results provide a systematic set of information from which trends of CO and HC idle emission differences between JP-4 and JP-8 may be deduced as a function of engine operating conditions.

J85-5 engine emissions are of special importance to the question of environmental impact. The most active Air Force Bases, those with a training mission, would be most seriously affected by the proposed fuel conversion.[4] Since the T38 trainer aircraft using the J85 engine is the predominant contributor to total aircraft emissions at these bases, results of the present J85-5 engine test are especially important in defining significant impacts of JP-4 to JP-8 conversion.

The results of this work provide input to sophisticated air quality impact models[4] which consider pollutant emission from all airbase sources, pollutant dispersion processes, climatology, temporal variations of source activity, etc. Air quality modeling is being undertaken by the Air Force Civil Engineering Center, Tyndall AFB. Preliminary study has confirmed the importance of using this approach; tradeoffs between the decreased evaporative losses with low volatility JP-8 and possible increased hydrocarbon exhaust emissions have been uncovered.

This report is organized into five further sections. In Section II, the <u>anticipated effects</u> of lower volatility JP-8 on pollutant emissions are evaluated. Section III reviews <u>available data</u> relevant to the subject. Sections IV and V discuss <u>new data</u> acquired during AFAPL T56 single combustor and J85-5 engine investigations. Finally, conclusions that may be drawn from this collection of information are summarized in Section VI.

SECTION II

BACKGROUND

The purpose of this section is to review the nature of pollutant formation and to discuss the variations in emissions between JP-4 and JP-8 which might be anticipated from present understanding. More detailed information concerning pollutant formation processes may be found in References 5 and 6.

A. HC and CO Emissions

Aircraft turbine engine combustors are designed for peak efficiency at cruise and higher power settings. Combustor conditions during idle and taxi operations are appreciably different from the cruise setting and the combustor operates less efficiently at these points. The major effect of inefficient idle operation is the emission of species which represent unused chemical energy--CO and HC. Emissions of these species at the other non-afterburning engine operating conditions are generally not considered significant.

During afterburning operation, significant quantities of CO, and sometimes HC, are present at the engine exhaust plane. However, extensive sea-level testing has shown that further chemical reactions in the exhaust plume sharply reduce emission levels.[7] This effect is most significant at maximum afterburner operation. Consequently, the CO and HC emission levels actually entering the environment are much reduced from the exhaust plane value, and are thought to be less significant than idle emissions.

Table 1 lists the JP-4 and JP-8 properties that might be expected to influence combustion efficiency or CO and HC emissions.

Table 1: Important Jet Fuel Properties

Property	JP-4 Spec Reqm't	JP-4 Typical Value	JP-8 Spec Reqm't	JP-8 Typical Value	JP-5 Spec Reqm't	JP-5 Typical Value
Vapor Pressure @ 100°F (psi)	2-3	2.7	-	0.1	-	0.05
Initial Boiling Point (°F)	-	140	-	335	-	360
End Point (°F)	-	475	550	510	550	500
Flash Point (°F)	-	-10	105	125	140	145
Aromatic Content (% Vol)	25	12	20	16	25	16
Olefinic Content (% Vol)	5	1	-	1	-	1
Saturates Content (% Vol)	-	87	-	83	-	83
Net Heat of Combustion (Btu/lb)	18,400	18,700	18,400	18,600	18,300	18,500
Specific Gravity	0.751-0.802	0.758	0.755-0.830	0.810	0.788-0.845	0.818

The properties of JP-5, used principally by the Navy, have also been included. Both specification requirements and typical properties of fuel actually supplied have been given. The principal difference affecting the combustion process involves fuel vaporization characteristics which are indicated by the parameters vapor pressure at 100°F and flash point. The flash point is an empirically measured temperature which indicates the condition at which the equilibrium vapor/air mixture above the liquid fuel surface reaches the lower flammability limit. Because of JP-4's higher vapor pressure characteristic, this condition occurs at a much lower temperature.

A very small portion of the fuel composition controls the flash point value. The presence of a small amount of highly volatile hydrocarbons is sufficient to cause a flammable vapor/air mixture at low temperature. Combustion of the balance of the fuel is further influenced by the vaporization characteristics at temperatures above the flash point. The vapor pressure versus temperature curves for JP-4 and JP-8 are shown in Figure 1. Iso-octane is also shown for comparison. Although the most significant differences are at the lower temperatures, appreciable differences occur at higher temperatures as well.

The effect of low volatility is to reduce liquid fuel vaporization rates in the combustor and decrease the time available for com-combustion reactions. This tends to reduce combustion efficiency and result in increased CO and HC emissions. The extent of this effect, however, is uncertain. Combustor temperature, pressure, and fuel-air ratio as well as combustor design could be expected to influence the

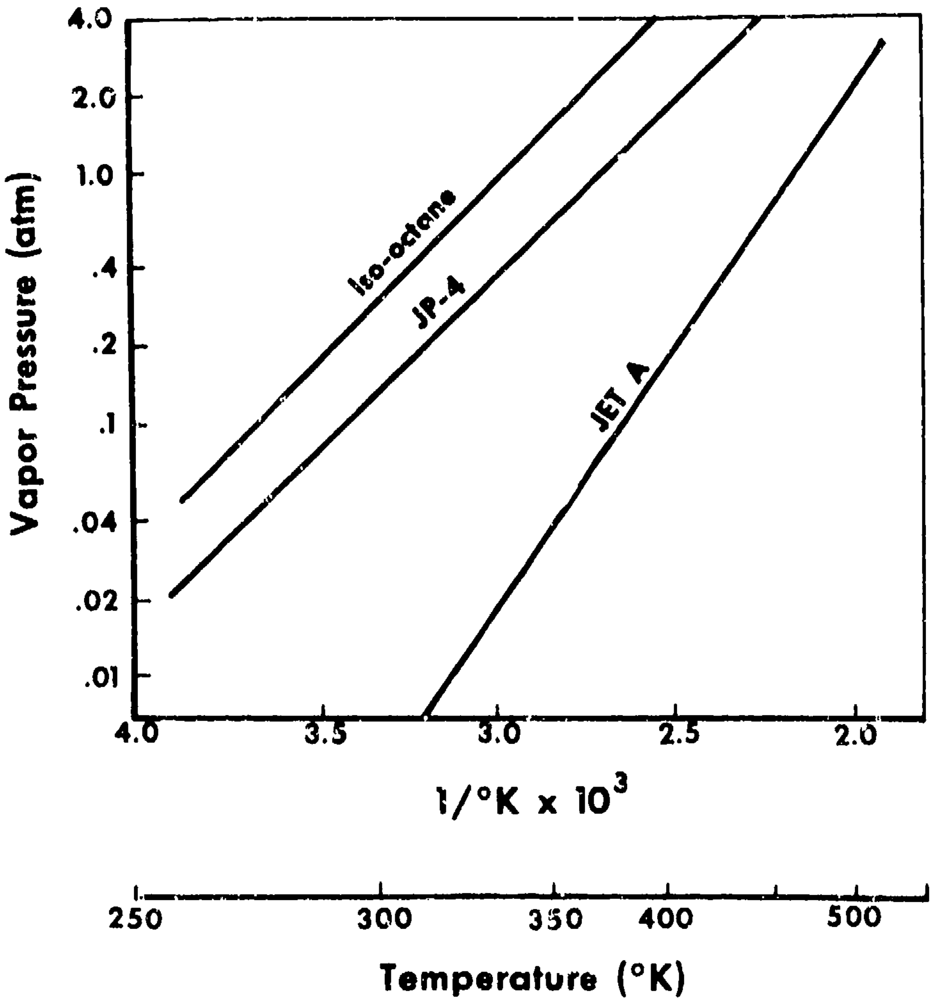

Figure 1: Jet Fuel Vaporization Characteristics

impact of lower volatility on CO and HC emissions.

B. NO_x Emission

Although highest at full power operation, the emission of NO_x is significant at takeoff, climbout, and landing approach. The problem stems from molecular oxygen and nitrogen in air being exposed to the extremely high temperatures of the main combustor primary zone. Fuel-air mixtures have been designed to be approximately stoichiometric in this zone for stability considerations. Increased combustor inlet temperatures due to the compression process cause the stoichiometric flame temperature to be exceedingly high. NO_x contributions from the afterburner are significantly less than the main burner because maximum temperatures achieved are much reduced.[7]

In non-aircraft gas turbine operations or in the case of future alternate (coal or oil shale derived) fuels for aircraft use[8,9] fuel bound nitrogen may result in a significant additional contribution to NO_x emission. Current jet fuels have very low fuel bound nitrogen levels (<20ppmw) and NO_x emission due to this contribution is not significant.

A reported correlation of data from many engines[10] has shown that NO_x emission during non-afterburning operation is strongly related to the combustor inlet temperature (See Figure 2). The NO_x emission index used in Figure 2 represents the total $NO + NO_2$ emission expressed in gm NO_2/kg fuel burned, calculated by considering the NO as NO_2. This data, obtained with current low nitrogen jet fuels, is not affected by fuel bound nitrogen NO_x

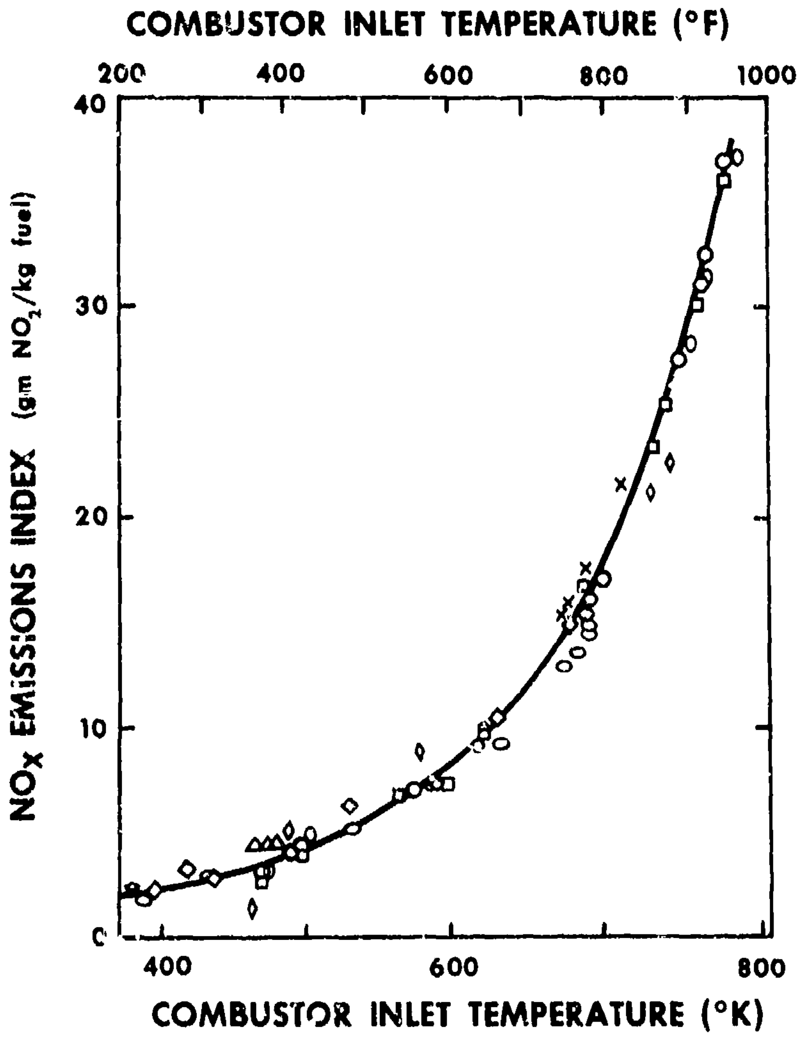

Figure 2: NO_x Emission Correlation with Combustor Inlet Temperature

contributions. Subsequent analysis of the NO_x formation process dependence on primary zone flame temperature has been used to explain this correlation and provide a basis for extrapolation of NO_x data to combustor conditions beyond those of present systems.[11-14]

An analytical model of NO_x formation[11] in non-afterburning aircraft gas turbine combustors has been utilized to predict the difference in sea-level NO_x emission that might be expected between JP-4 and JP-8. The principal fuel variables are the heat of combustion (or heat of formation) and fuel hydrogen content. Table 2 illustrates these parameters, the calculated primary zone flame temperature*, and a predicted NO_x emission index. These results are shown for three different engine cycle pressure ratios, 10, 20, and 30. In no case do the results indicate significant differences. Consequently, it is anticipated that a conversion from JP-4 to JP-8 would have no significant impact on sea-level NO_x emission during non-afterburning operation.

Although no analogous model of afterburner NO_x formation has been employed, the similarities in flame temperature and NO_x formation mechanism strongly imply that NO_x emission differences during afterburner operation are also insignificant.

C. Smoke Emission

Visible smoke emitted from aircraft turbine engines is principally composed of particulate carbon. Although some particulate material is produced by all engines, significant smoke is generated in systems which operate unusually fuel-rich in local zones of the combustor. It has been established that the presence of exhaust

* The fuel-air ratio of 0.9 stoichiometric which has been used for this calculation represents the condition for maximum NO formation rate.

Table 2: Predicted JP-4 and JP-8 NO_x Emission

Fuel	Heat of Combustion (cal/gm)	Hydrogen Content (wt%)	Combustor Inlet Temperature (°K)	Combustor Inlet Pressure (atm)	Calculated Primary Zone Flame Temperature * (°K)	Predicted NO_x Emission Index ($gmNO_2$/kg fuel)
JP-4	10,388	14.4	590	10	2393	11.1
			720	20	2487	29.4
			810	30	2551	55.8
JP-8	10,333	13.95	590	10	2393	11.1
			720	20	2487	29.2
			810	30	2550	55.3

* Primary Zone Equivalence Ratio of 0.9 Assumed

smoke has little effect on the overall performance of the engine system--combustion inefficiency associated with this emission is negligible. Nevertheless, the aesthetic nuisance and tactical vulnerability arising from smoke emission has required that the problem be eliminated. The engineering capability to design smokeless combustors is in hand and the most modern engines have been designed to emit no visible smoke.

The technique developed by Society of Automotive Engineers Committee E-31 to measure smoke[15] involves passing a known volume of exhaust through filter tape to create a smoke spot. The reflectance of the spot is used to determine a smoke number (SN). Although the relationship between this measurement and actual exhaust plume visibility is complicated, a general correlation is presented in Figure 3. This correlation is presently used as a guideline for specification of SN in USAF engine procurements.

All results presented in this report are given in terms of the SAE Smoke Number. However, environmental analysis may require this information to be interpreted as either an emitted particulate concentration (mg/m^3) or as an emission index. Such correlations have been developed (References 16 and 6) and are presented in Figure 4.

Of the JP-4 and JP-8 characteristics listed in Table 1, two properties would be expected to affect smoke emission. First, decreased fuel volatility tends to preserve rich fuel-air ratio pockets in the combustor which promotes the formation of smoke.

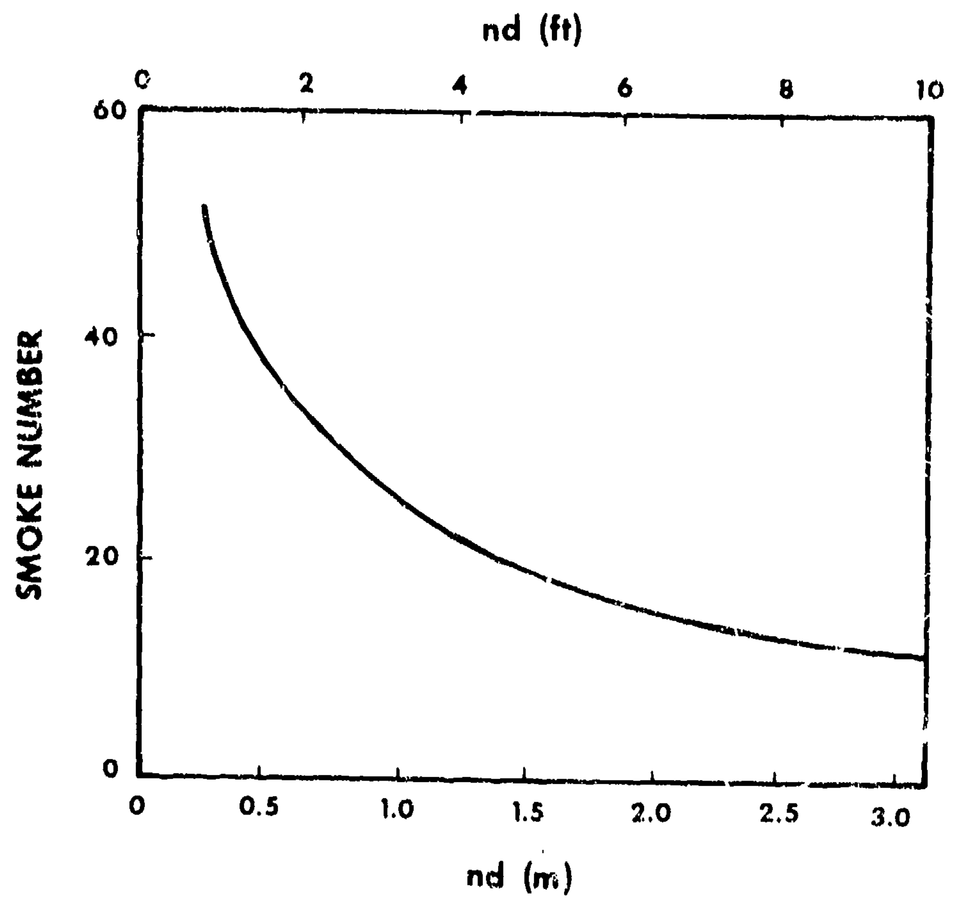

Figure 3: Smoke Emission Visibility Criteria

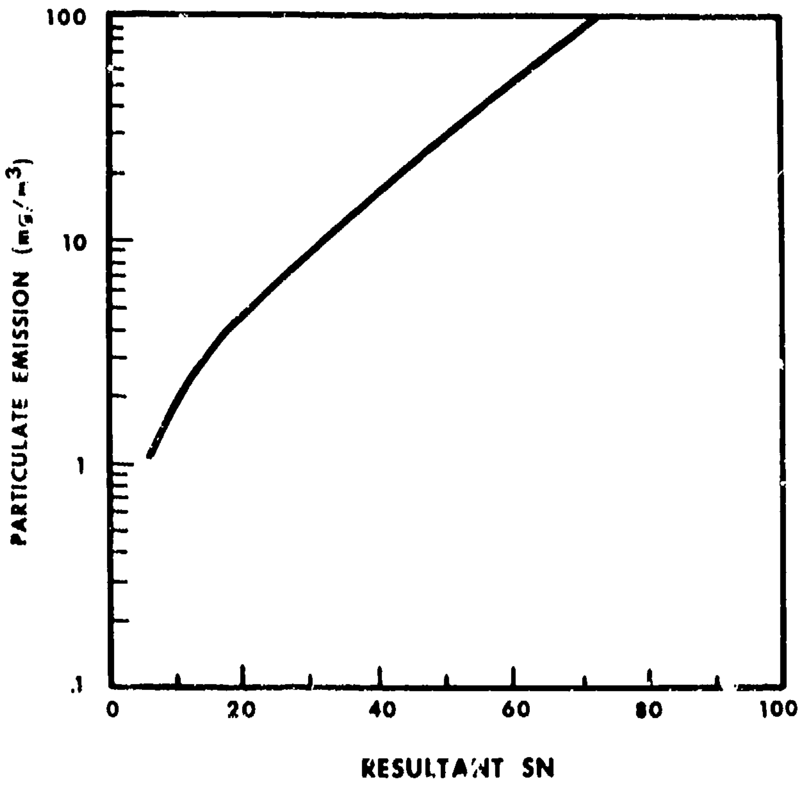

Figure 4: Relationship Between Smoke Number and Particulate Emission

Secondly, increased fuel aromatic concentration causes the fuel to have a lower hydrogen content which also promotes the formation of smoke. An example of the distinct relationship between smoke emission and fuel hydrogen content for a particular aircraft combustion system (the T56) is shown in Figure 5. Since JP-8 is both less volatile and typically higher in aromatic content than JP-4, smoke emission is anticipated to be greater with JP-8.

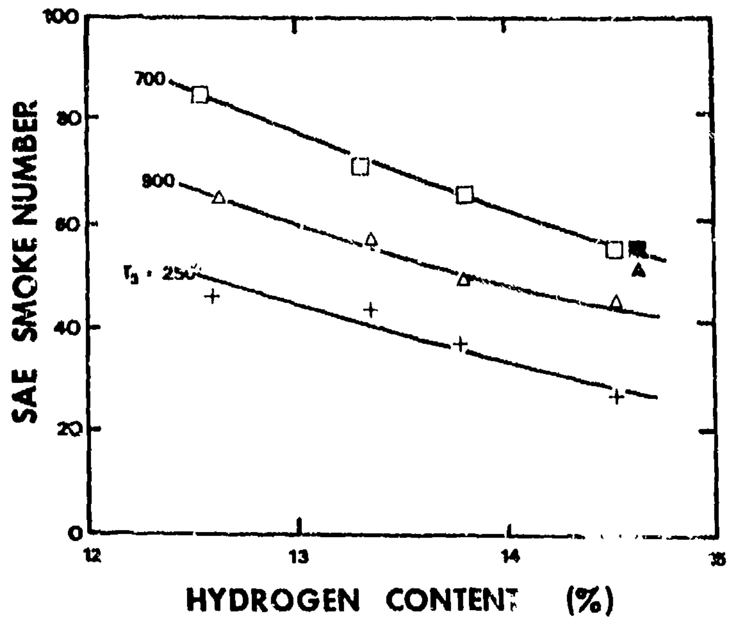

Figure 5: Smoke Emission Dependence on Fuel Hydrogen Content

SECTION III

PREVIOUS DATA

Previous investigations of fuel effects on emissions have included both combustor rig and engine studies. In the case of combustor rig testing, a reproducible set of combustor inlet and operating conditions could be obtained for the purpose of determining the effects of a change in fuel only. This is a much more favorable situation than engine data, where control of combustor conditions is not usually possible.

Numerous engine emission data banks exist which include data obtained using different fuel types.[17,18] However, because of significant effects of ambient conditions, engine to engine variability, and measurement inaccuracy, data is generally considered to be useful only if the two fuels were tested on the same engine in a controlled manner or where a significant number of engines were examined on each fuel.

Much of the available data has been obtained by contrasting JP-4 with JP-5 rather than JP-8. Because the combustion characteristics of JP-8 and JP-5 are similar (See Table 1), the JP-5 comparisons are assumed to be representative of those which would have been obtained with JP-8.

A. Combustor Rig Data

Detroit Diesel Allison Division of General Motors studied JP-4 and JP-5 emissions in a T-63 combustor, model 250-C20B.[19] This testing involved combustor inlet pressures from 3 to 7 atmospheres, inlet temperatures from 425°K, and fuel-air

ratios from .0016 to .022. The HC, CO, and NO_x results have been plotted in Figures 6, 7, and 8 as a function of percent horsepower output. These data indicate that idle (lowest horsepower output) HC emissions with JP-5 were significantly greater than with JP-4. On the other hand, CO emissions do not appear to differ by a large amount for the two fuels. However, it is surprising that the CO emission with JP-5 appears to be less than in the case of JP-4. No consistent differences were found for the NO_x emission with the two fuels. In the case of smoke emission, a significant increase was indicated for the JP-5 fuel. These results are shown in Figure 9. This effect is consistent over the entire range of engine power output.

General Electric Company (Aircraft Engine Group), has reported results of F101 PV sector testing where HC and CO emissions data were reported for JP-4 and JP-5 fuels.[20] The data were obtained at inlet conditions corresponding to engine idle (3.2 atm and 437°K) with fuel-air ratio being varied as an independent parameter. No differences between JP-4 and JP-5 HC or CO emissions were noted.

B. Engine Test Data

General Electric has examined the effects of fuel type on emissions for three engine models (CJ805 or J79, F101, and TF39). In each case the fuels tested were JP-4 and JP-5.

The effects of fuel type on smoke emission from a CJ805 engine (which is representative of a J79) equipped with a low smoke combustor system were studied.[21] The J79 engine is a 17,000 lb_f thrust engine having a compressor pressure ratio of 12.9 and a

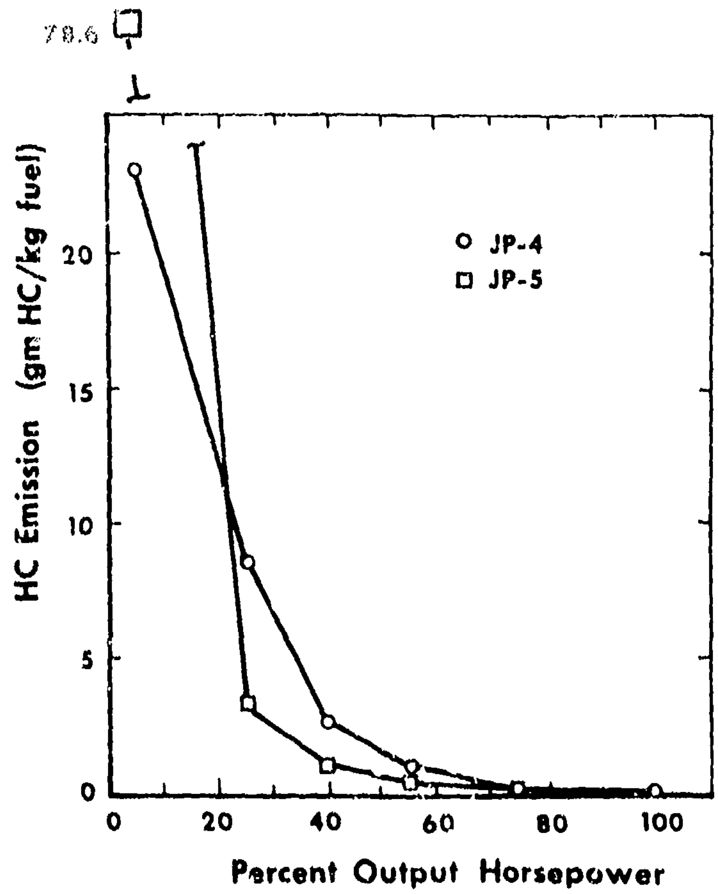

Figure 6: Effect of Fuel Type on HC Emission from a T63-Type Combustor

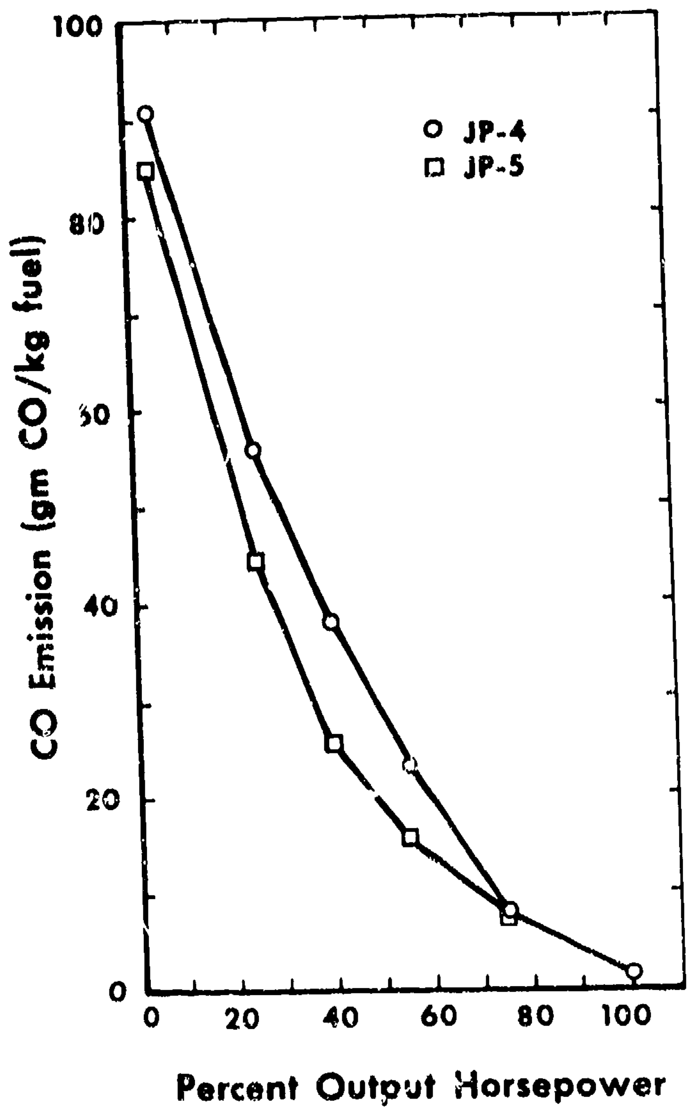

Figure 7: Effect of Fuel Type on CO Emission from a T63-Type Combustor

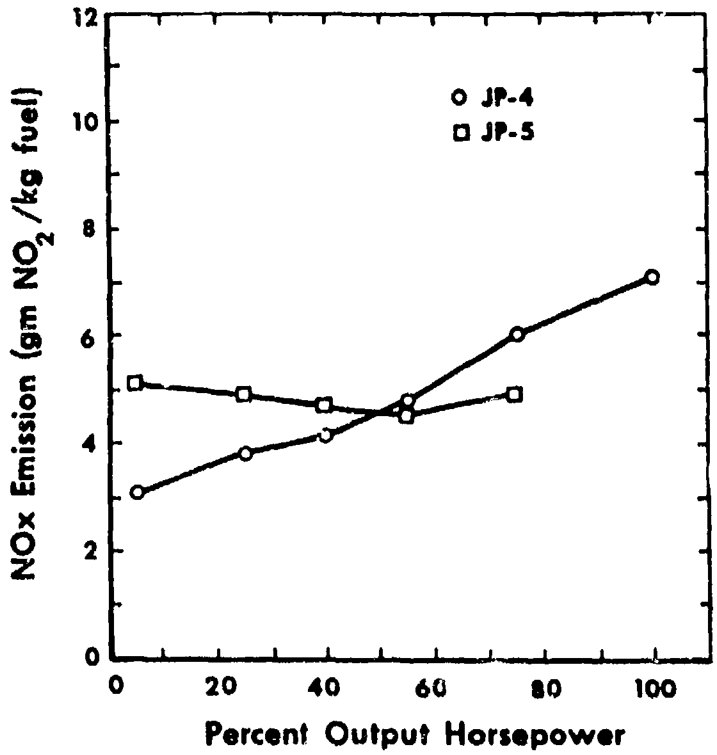

Figure 8: Effect of Fuel Type on NO_x Emission from a T63-Type Combustor

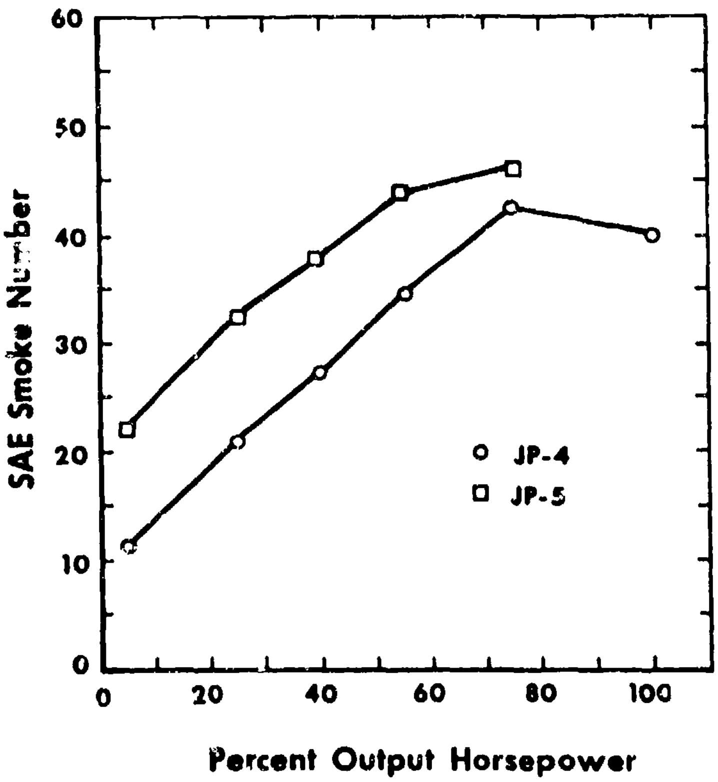

Figure 9: Effect of Fuel Type on Smoke Emission from a T63-Type Combustor

main combustion system which is can-annular in design. This engine is representative of many engines currently in the Air Force inventory. Figure 10 illustrates the measured smoke emission as a function of corrected fuel-air ratio. Note that under all conditions smoke number was significantly increased with the use of JP-5 fuel.

A TF39 engine was tested using JP-4 and JP-5 fuels.[22] The TF39 is representative of the more modern technology in the current AF engine inventory. This high bypass ratio engine has a cycle pressure ratio of about 25 and employs an annular combustion chamber. Three fuel nozzle designs were employed during this test program. The smoke number results for operation with each nozzle consistently indicated higher smoke emission with the use of JP-5. HC, CO, and NO_x testing indicated no difference between JP-4 and JP-5.

F101 engine testing, using the PFRT combustor, was undertaken to determine JP-4 and JP-5 gaseous emission levels.[23] The F101 is representtative of engines which will be entering the Air Force inventory over the next decade. An important feature of the F101 annular combustion system is the use of a low fuel pressure air blast atomization carburetor. Results of this study are presented in Figures 11 and 12. Although it is difficult to draw definite conclusions with the use of a single JP-4 data point, the JP-5 HC emission does not appear to differ from the JP-4 value while the CO emission does appear to be significantly increased. It is not possible to determine the impact on NO_x with the single JP-4 data point corresponding to idle conditions where NO_x emission is lowest.

Pratt and Whitney Aircraft Division has studied the effect of fuel

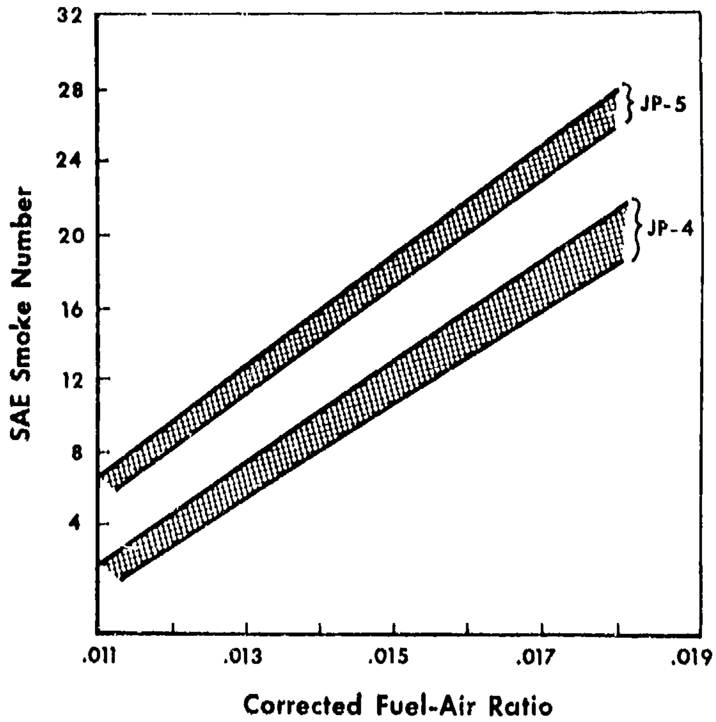

Figure 10: Effect of Fuel Type on Smoke Emission from a CJ805 (J79) Engine with Low-Smoke Combustor

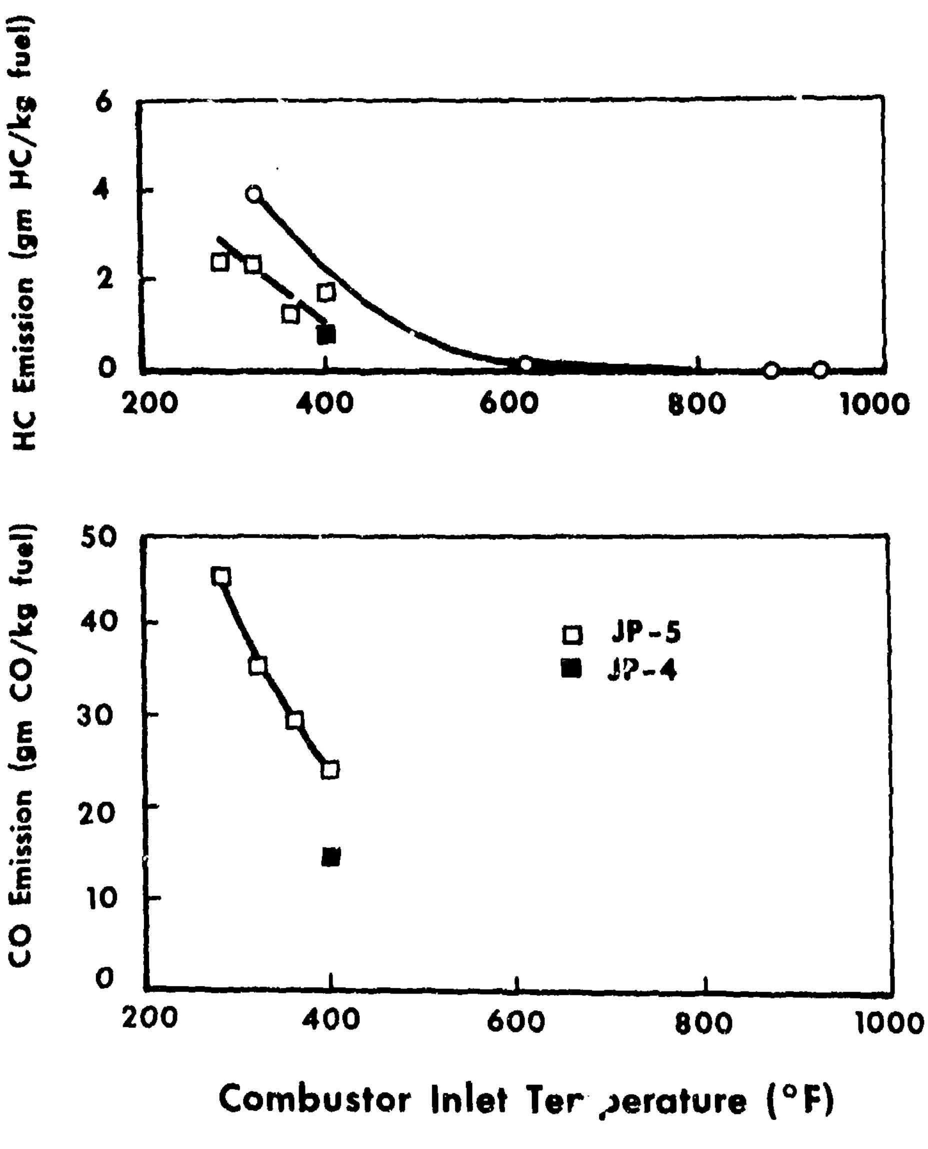

Figure 11: Effect of Fuel Type on HC and CO Emissions from an F101 Engine (PFRT Combustor)

type on gaseous emissions from a collection of nineteen production JT9D engines.[24] The JT9D represents a similar technology to the TF39 previously discussed. Eleven engines were tested on JP-4 fuel with the remainder being tested on Jet A (JP-8). The results indicated no differences in gaseous emissions with the change in fuel type.

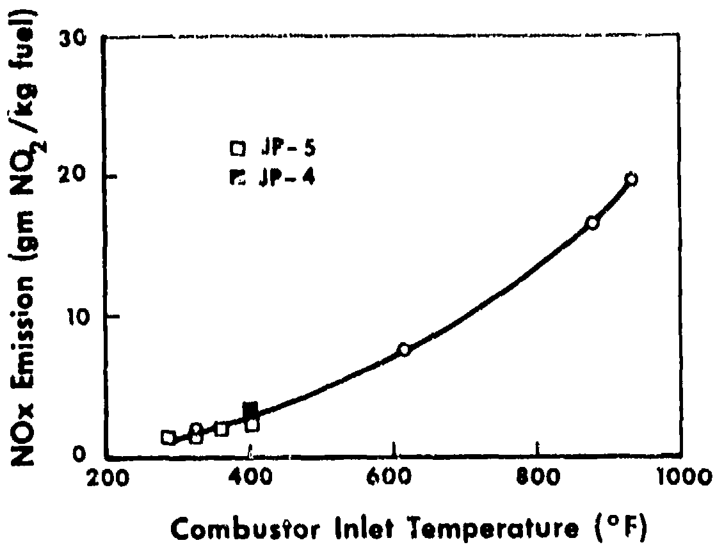

Figure 12: Effect of Fuel Type on NO_x Emission from an F101 Engine (PFRT Combustor)

SECTION IV

SINGLE COMBUSTOR TESTING

To better assess fuel effects on idle CO and HC emissions, data were systematically obtained at AFAPL on a T56 single combustor under inlet pressure and temperature conditions intended to represent a variety of engine idle conditions.

A. Experimental

The AFAPL combustion facility is capable of providing up to 3.4 kg/sec of air at pressures up to 18 atm and temperatures up to 727°K. At pressures below 6.5 atm, 8 kg/sec air can be supplied at temperatures up to 840°K. Heating is accomplished by a nonvitiated natural-gas-fired furnace. Single can as well as sectors of annular combustors may be tested.

Figure 13 is a photograph of the combustor rig utilized in the subject study. Accurate control of combustor pressure and air flow is accomplished by using an automatic air bleed control which senses pressure and an exhaust plug which may be remotely operated from the control room. This exhaust system is not visible in the figure because of the noise muffling system employed. Measurement of air flow is accomplished by the use of a venturi having a 5cm diameter throat. Fuel flow is determined from a turbine flow metering device. Combustor inlet and exhaust temperatures are measured using chromel-alumel thermocouples.

The test combustor was a T56 series IIIA single combustor. The T56 is a turboprop engine used in the C-130 aircraft. Six single combustors of the type tested (see Figure 14) are arranged in an annular fashion in the engine. This combustor was chosen because

Figure 13: T56 Single Combustor Rig System

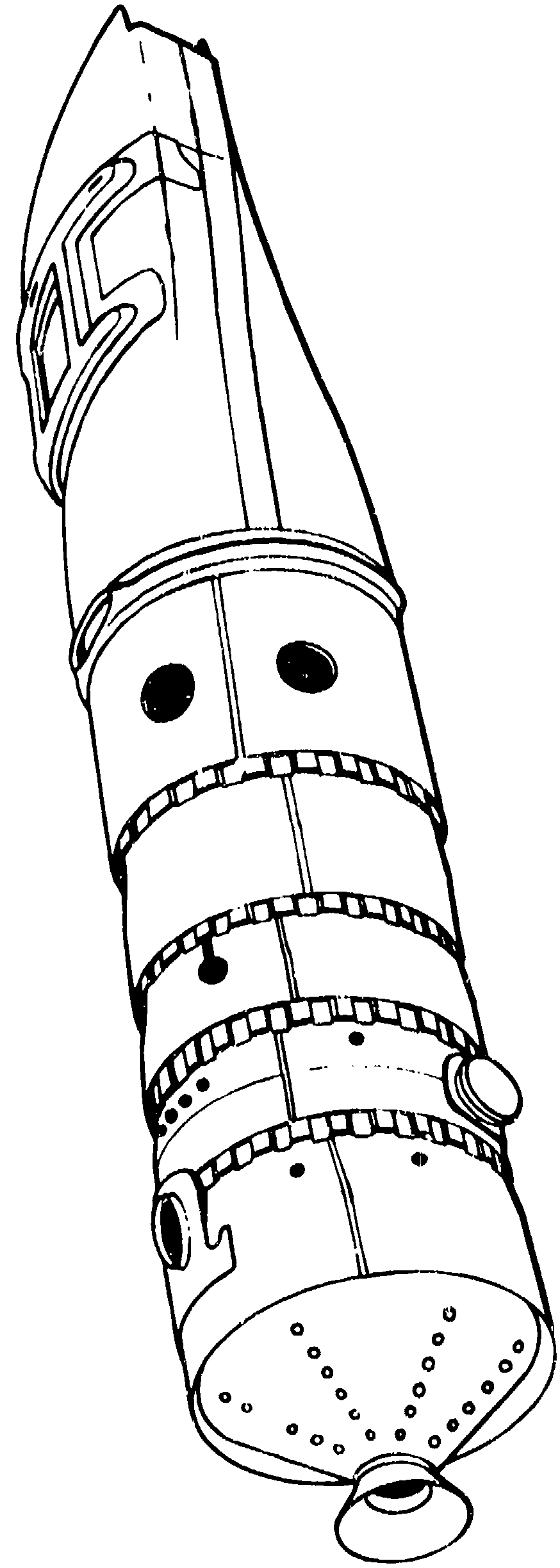

Figure 14: T56 Single Combustor

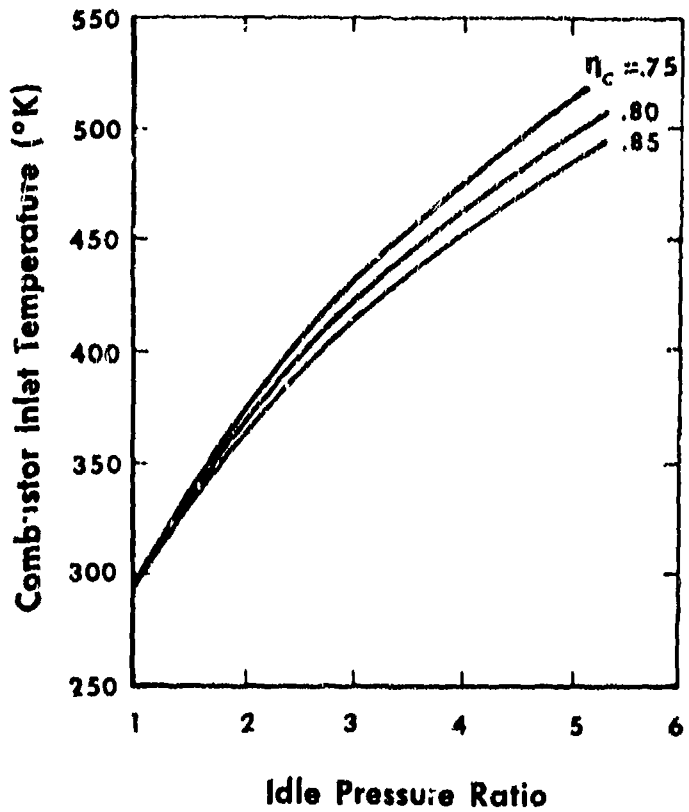

Figure 15: Combustor Inlet Temperature Dependence on Pressure Ratio at Idle

of its availability and proven operation of the AFAPL combustor rig system.

Engines vary significantly in idle operating condition with pressure ratios ranging from 1.4 to 5.0. Combustor inlet temperature may be related to pressure ratio through isentropic relationships and knowledge of the compressor efficiency, η_{comp}. Figure 15 graphically illustrates the relationship for the range of idle pressure ratios of interest at compressor efficiencies of .75, .80, and .85. Ambient conditions for standard day operations (288°K, 1 atm, and 0% humidity) were assumed in generating this graph.

Although specific combustor pressure, temperature and air mass flow rate conditions correspond to T56 engine idle operation, these parameters were scaled in the subject experiment to simulate the idle operation of other engines. The inlet pressure and temperature conditions were controlled to correspond to those of Figure 15 for a compressor efficiency of 0.80. Mass flow was scaled to simulate a constant compressor discharge Mach number. This resulted in mass flow scaling as $PT^{-1/2}$, where P and T are absolute pressure and temperature. The fuel-air mass ratio was kept at 0.0078 for all tests.

Exhaust gases were extracted through a stainless steel probe located approximately ten centimeters behind the combustor exit. The temperature of the probe was controlled by a heated water system which insured that water or hydrocarbon condensation did not occur within the probe while excessive probe temperatures would not be reached. The range of temperatures encountered in sample transport was 100 - 160°C. All other gas sampling system details were designed to be consistent with the recommendations of

Society of Automotive Engineers ARP 1256[25] with the following exceptions: a) use of an unheated sample line between the sample manifold and the NO/NO_x analyzer, and b) the use of Drierite desiccant rather than a water/ice bath to remove water from sample entering the CO and CO_2 analyzers.

The instrumentation used was as follows: A Beckman Model 402 FID Hydrocarbon Analyzer for hydrocarbon measurement, a ThermoElectron Corp. Model 10A Chemiluminescence Analyzer for NO and NO_x measurement, and Beckman Model 315B NDIR Analyzers for CO_2 and CO measurement. It is noted that CO_2 readings were collected for use in a carbon balance which was used to verify that the sample obtained was representative; the fuel-air ratio calculated from gas analysis is compared to that from fuel and air flow measurement. Data is generally not considered acceptable unless the two results agree to within $\pm$15%.

The characteristics of the actual JP-4 and JP-8 fuels used in the combustor rig testing are shown in Table 3.

B. Results

Hydrocarbon data obtained with JP-4 and JP-8 in the T56 single combustor are illustrated in Figure 16. The results are reported versus the idle pressure ratio being simulated. The data indicate that HC emissions with JP-8 significantly exceed those for JP-4 at all simulated idle pressure ratios. These data are re-plotted in Figure 17 to illustrate the ratio of the HC emissions index value for JP-8 to that for JP-4. An increasing trend for this ratio with pressure ratio is noted.

CO emissions results are presented in Figure 18. Again JP-8 emissions exceed those obtained using JP-4 for all pressure ratios

Table 3: T56 Test Fuel Characteristics

Property		JP-4	JP-8
Specific Gravity		.753	.802
Aniline Point (°F)		143	147
Smoke Point (Smoke Volatility Index or mm)		64.5(SVI)	25mm
Aromatics (% Vol)		9.0	13.0
Distillation	IBP(°F)	148	286
	10%	210	340
	20%	220	364
	50%	290	410
	90%	438	480
	End Point	478	506
Flash Point (°F)		-	112
Vapor Pressure @ 100°F		2.4	-

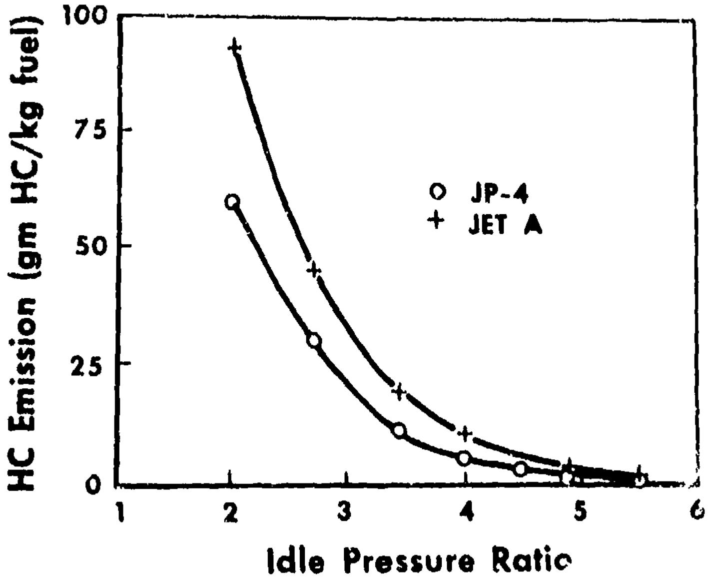

Figure 16: HC Emission Dependence on Fuel Type in the T56 Combustor

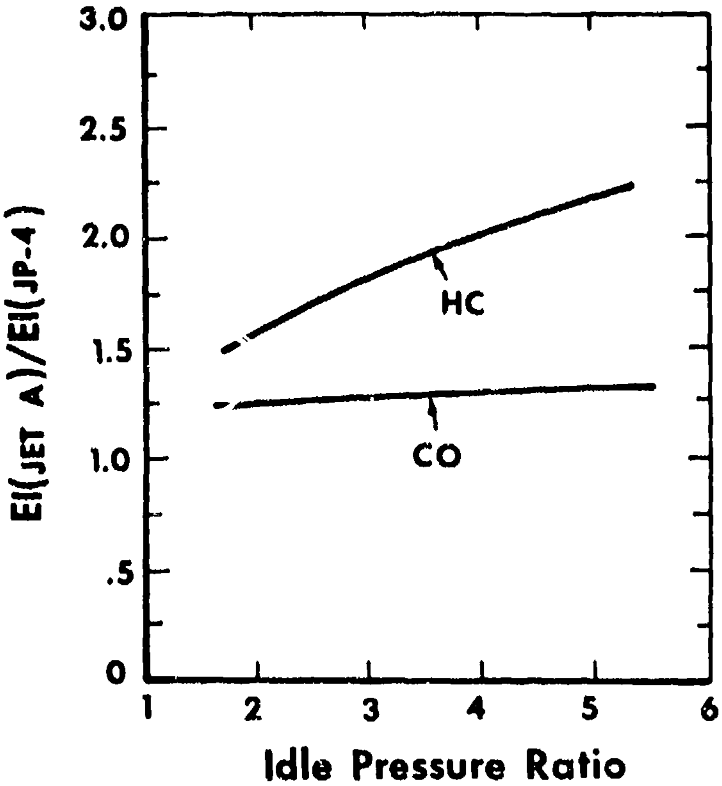

Figure 17: HC and CO JP-4 to JP-8 Emission Ratios

studied. However, the differences between JP-8 and JP-4 CO emissions are much less substantial than in the case of HC. The JP-8/JP-4 CO emission index ratio is illustrated in Figure 17 as a function of pressure ratio.

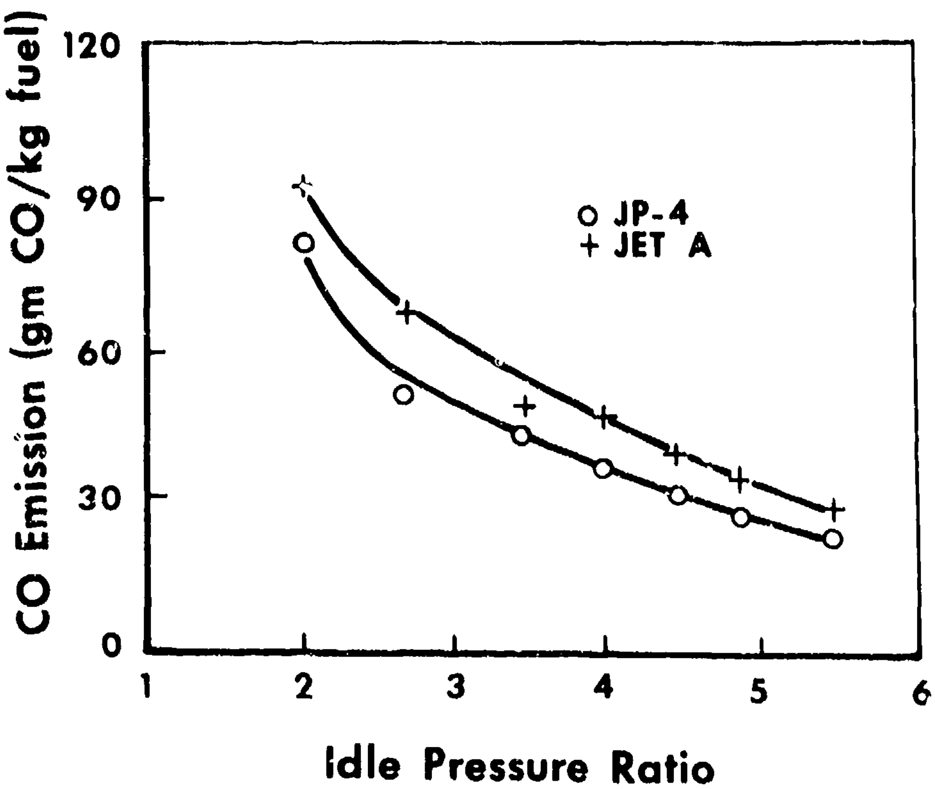

Figure 18: CO Emission Dependence on Fuel Type in the T56 Combustor

SECTION V
J85-5 ENGINE TESTING

A. Experimental

A J85-5 afterburning turbojet engine installed in a sea-level engine test stand at AFAPL was utilized to study JP-4 and JP-8 emissions rates. Figure 19 illustrates the facility with the engine installed. The J85-5 engine has a maximum compression ratio of 7.0 and an annular combustion chamber. The afterburner employs a single flameholder with four pilot modules and a variable area exhaust nozzle. Engine airflow at military operation is 44 pounds per second and maximum thrust is 3850 pounds.

Three three-hour tests were run during this program. The first test was undertaken using a typical JP-4 fuel. JP-8 was examined in the second test and finally, the typical JP-4 baseline was repeated. Each 3-hour test consisted of nine twenty minute cycles involving the following series of operations:

Idle	5 minutes
Military	5 minutes
Afterburning*	5 minutes
Normal	5 minutes

A three-hour test required approximately 1200 gallons of fuel.

The characteristics of the JP-4 and JP-8 tested are listed in Table 4. Note that the JP-8 test fuel had a flash point of 95°F which was below the specification limit of 105°F. The JP-8 used in this testing was apparently contaminated with JP-4 during handling prior to or during testing. This small difference is not thought to have a significant effect on the results.

*Fuel-Flow into the afterburner was set at 5000 lbm/hr for this condition.

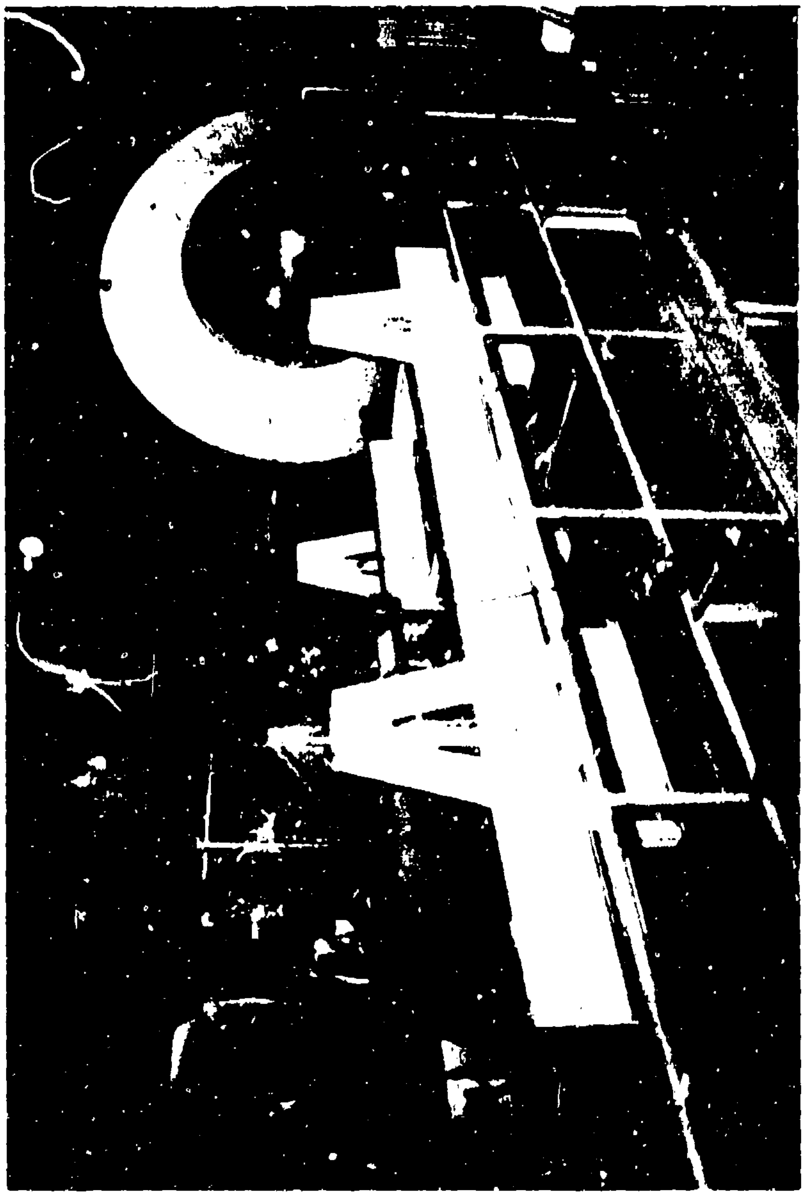

Figure 19: J85-5 Engine in Sea-Level Test Stand

Table 4: J85 Test Fuel Characteristics

Property		JP-4	JP-8
Specific Gravity		.755	.805
Aniline Point (°F)		140.	141.
Smoke Point (Smoke Volatility Index or mm)		62.9(SVI)	24mm
Aromatics (% Vol)		9	14.0
Distillation	I BP(°F)	149	295
	10%	210	352
	20%	230	371
	50%	286	404
	90%	432	469
	End Point	476	505
Flash Point (°F)		-	95
Vapor Pressure @ 100°F (psi)		2.4	-

Exhaust gas emissions and smoke were measured at all operating conditions except afterburning (because the sample probe used could not withstand these high exhaust temperatures). A single-point sample probe was used to extract gases used in these measurements. The sample line was heated to prevent water or hydrocarbon condensation. The total system generally conformed to the ARP 1179 and 1256 requirements[15,25] with the exception of sampling location. This was about 12 feet downstream (after appreciable exhaust dilution or sample averaging) where the single sample was acquired. Emission index values were calculated using the gas analysis data only. Carbon monoxide and carbon dioxide measurements were accomplished with Beckman Model 315 non-dispersive infrared instruments, hydrocarbons were sensed within a Beckman Model 402 flame ionization detector, and NO_x was measured using a Thermo Electron chemiluminescence analyzer. Smoke was measured with the same system used in the T56 single combustor testing.

Performance parameters of importance were also measured. These included engine thrust, airflow, main combustor fuel flow, afterburner fuel flow, compressor discharge pressure, and turbine exit temperature. Note that significant changes in afterburner combustion efficiency (or CO and HC emissions) could be inferred from the thrust and fuel consumption measurements if differences between JP-4 and JP-8 results were indicated.

The nine hours of testing were accomplished in two consecutive days, 16-17 October 1975. Ambient variations during testing were small (ambient temperature 10-12°C, due point 5-7°C, and barometric pressure 760-771 mm Hg) and the data is not likely to have been affected by this potential error source.

B. Results

Reduced emissions data from the J85-5 engine test are indicated in Table 5. The only carbon monoxide instrument range operable during the test (0 - 5000 ppmw) could not give accurate results at the lower CO levels present at conditions other than idle. Consequently, CO data for power conditions above idle are not given. Smoke number measurements were also of limited use, as the levels detected for both fuels at all operating conditions were below the range where significant differences could be determined.

A statistical analysis was performed to determine the significance of the differences indicated. The only instance in which the JP-8 result was significantly different from both sets of JP-4 data is the case of idle CO emissions, where the JP-8 emissions are lower. All other differences are not significant to the 90% confidence limit established for the statistical test.

No significant thrust or fuel consumption differences were noted for afterburner operation using JP-4 versus JP-8. This implies that afterburner combustion efficiency or CO and HC emissions were not significantly affected by operation with JP-8 fuel.

Table 5: J85-5 Engine Emission Data

	CO Emission Index			HC Emission Index			NO_x Emission Index		
	JP-4	JP-8	JP-4	JP-4	JP-8	JP-4	JP-4	JP-8	JP-4
IDLE	165	147	161	18.7	19.0	22.2	1.33	1.07	.833
MILITARY	-	-	-	1.34	1.48	1.2	3.01	3.05	2.87
NORMAL	-	-	-	1.63	1.88	1.62	2.77	2.95	2.72

SECTION VI
CONCLUSIONS AND RECOMMENDATIONS

The proposed conversion of predominant Air Force fuel usage from JP-4 to JP-8 has created the need to examine the dependence of engine pollutant emission on fuel type. Examination of pollutant formation processes and the characteristics of JP-4 versus JP-8 implies the following anticipated changes upon conversion to JP-8: a) possible increases in HC and CO, b) no change in NO_x emission, and c) an increase in smoke/particulate emission.

A total of eight combustor rig or engine tests have been discussed in this report. Table 6 lists all the results presented. The findings may be summarized as follows:

a. Smoke emission is greater for the use of JP-8 (or JP-5) in each case investigated. Discussion in Section II indicated reason to anticipate this effect.

b. NO_x emission is not dependent on the jet fuel type employed. Application of an analytical model in Section II led to the same conclusion.

c. Idle HC emissions were significantly increased (100%) using JP-8 in the T63 or T56 combustors while not being significantly affected in five other tests.

d. Idle CO emissions were increased with JP-8 in the case of the T56 combustor and F101 engine tests while decreasing in the case of the T63 combustor and J85 engine tests. In three other cases CO emission was not affected. These changes are small (25%) in comparison with the hydrocarbon variations.

Table 6: Summary of JP-4/JP-8 Emission Results

Combustor/Engine Tested	Emission Change* HC	CO	NO_x	Smoke
T63 Combustor Test (model 250-C20B)	+	-	0	+
F101 PV Combustor Test	0	0		
J79 Engine Test				+
TF39 Engine Test	0	0	0	+
F101 Engine Test	0	+		
JT9D Engine Tests	0	0	0	
T56 Combustor Test	+	+		
J85-5 Engine Test	0	-		

* Change resulting from use of JP-8: - Decrease

0 No change

\+ Increase

It must be concluded that the effects of fuel type on HC and CO emissions are functions of the combustor design. Therefore, unlike the case of NO_x and smoke emission, no general statement regarding the effect of fuel conversion HC and CO emission can be made.

The implications regarding environmental impact of the proposed Air Force conversions from JP-4 to JP-8 are as follows. First, the primary changes expected would be in hydrocarbons and smoke emission; CO emission changes were not large enough to cause significant impact. Secondly, each base for which a potential problem is suspect must be individually studied. The type of aircraft at each base would be expected to affect conclusions regarding the impact on ambient hydrocarbon concentrations. In addition, reductions in fuel evaporative losses with the use of JP-8 must be considered in assessments of ambient air quality impact. For example, a preliminary study of Williams AFB indicated that decreased JP-8 evaporative losses could counterbalance an 11% increase in exhaust hydrocarbon emission.[26] Third, it is fortuitous that the J85 engine was found to be not sensitive to changing fuel type, for training bases (where the J85 is a high-use engine employed on the T38 aircraft) are among the most active and highest potential problem bases.

It is recommended that these results be utilized for further applications of available air quality analytical techniques. In addition to providing preliminary information regarding possible ambient air quality impact, these studies should identify areas where additional emissions data are required, especially with respect to increased HC and smoke emission. Further, existing combustor analytical models (particularly Reference 27) should be utilized to attempt prediction

of the emission results discussed in this report. Should these models be successful, analytical prediction of JP-8 emissions from other Air Force engine models may be substituted for more expensive engine testing.

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